R&D on CSP and Solar Chemistry in Europe

International Workshop on R&D, and

EDUCATION for NEXT GENERATION SOLAR HYDROGEN ENERGY SYSTEM

Niigata University, December 16th, 2014

Dr. Christian Sattler

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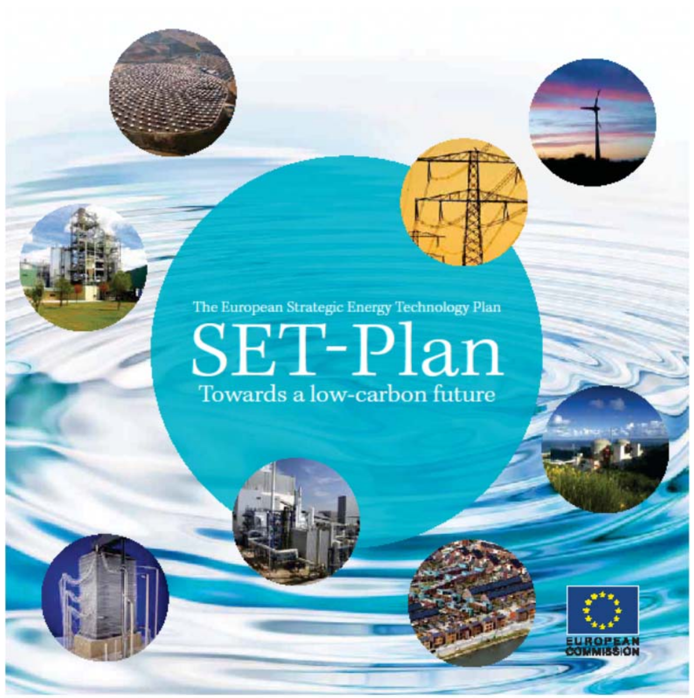
DLR

Political view: Sustainable Energy Technology Plan SET-Plan (2007) European Strategic Plan for Energy Technology

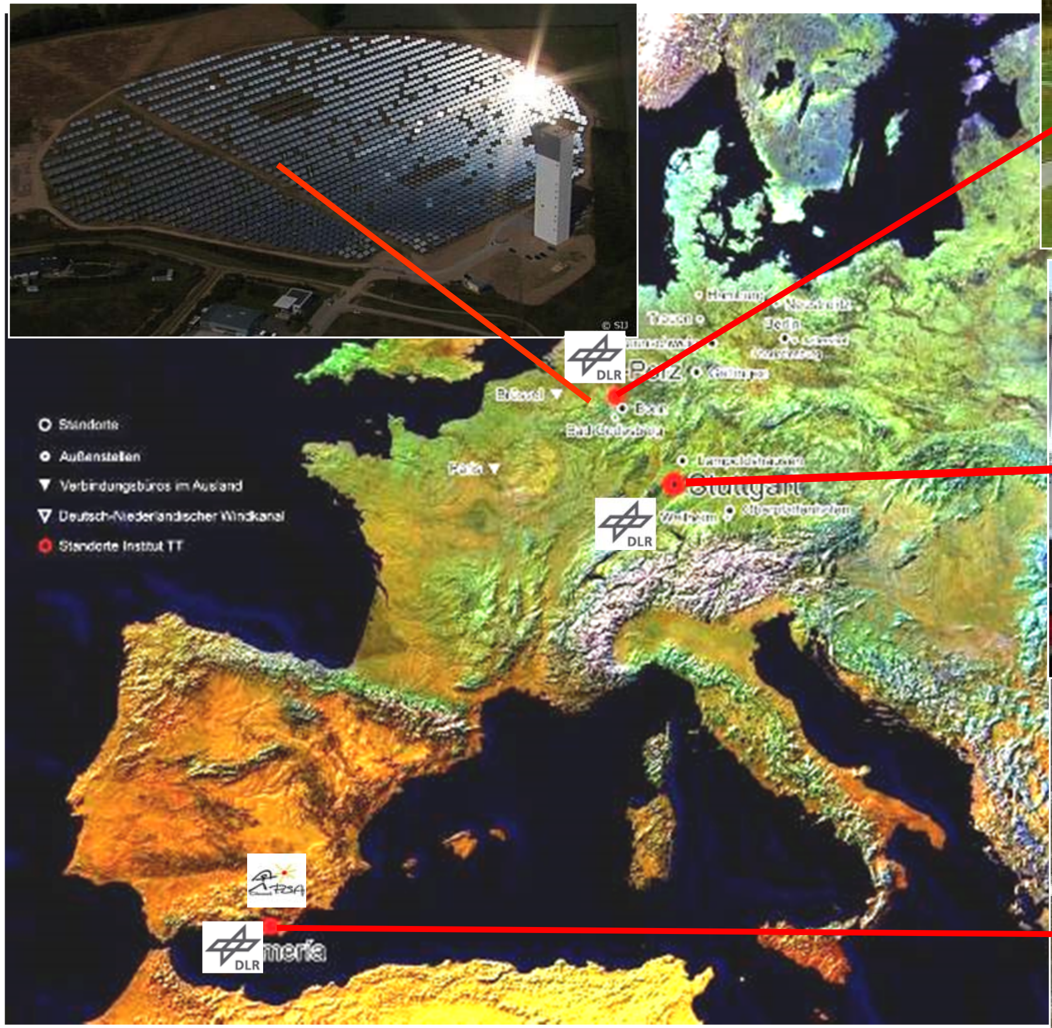
- **Goals of the EU until 2020 (20/20/20)**
  - **20%** higher energy efficiency
  - **20%** less GHG emission
  - **20%** renewable energy
- **Goal of the EU until 2050:**
  - **80%** less CO_2 emissions than in 1990
- Actions in the field of energy efficiency, codes and standards, funding mechanisms, and the charging of carbon emissions necessary
- Significant research effort for the development of a new generation of CO_2 emission free energy technologies, like
  - Offshore-Wind
  - **Solar**
  - 2nd generation Biomass



Programs in Europe

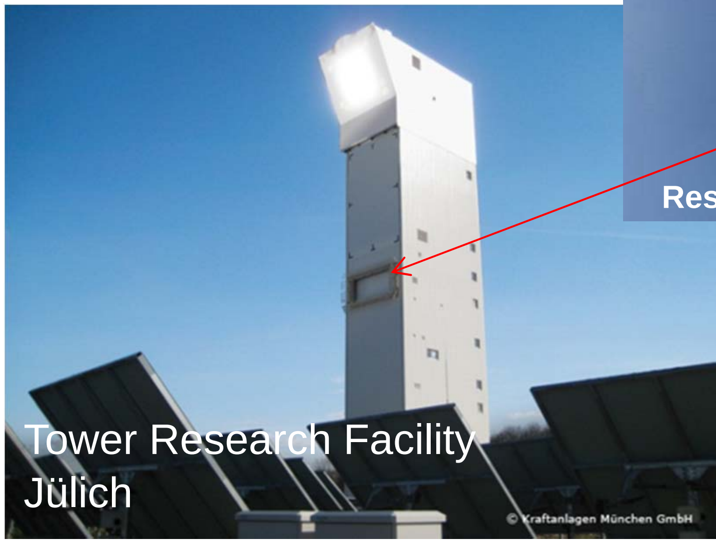
- **National Energy Research Programs** in most of the European Countries (very different levels and aims)
- **German Solar Fuels Program** was evaluated as outstanding this year and will be the fastest growing topic on renewable energy in large scale research over the next five years
- Joint Programs under the **European Framework Programmes** for Research and Technical Development (RFP)
- 2014 – 2020 **„HORIZON 2020“** - Wider focus than the previous seven RFPs: It combines all **research and innovation funding** provided through the RFP, the innovation related activities of the Competitiveness and Innovation Framework Programme (CIP) and the European Institute of Innovation and Technology (EIT)
- **Participation of partners from outside the European Research area**

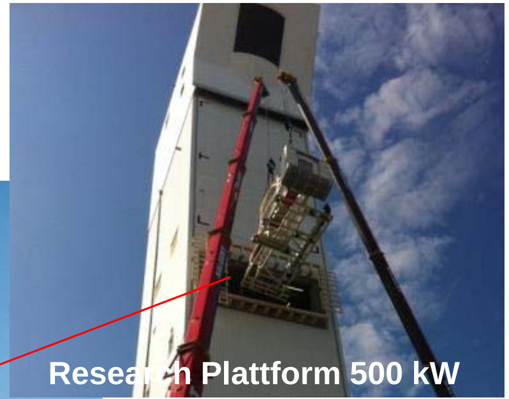
DLR Institute of Solar Research

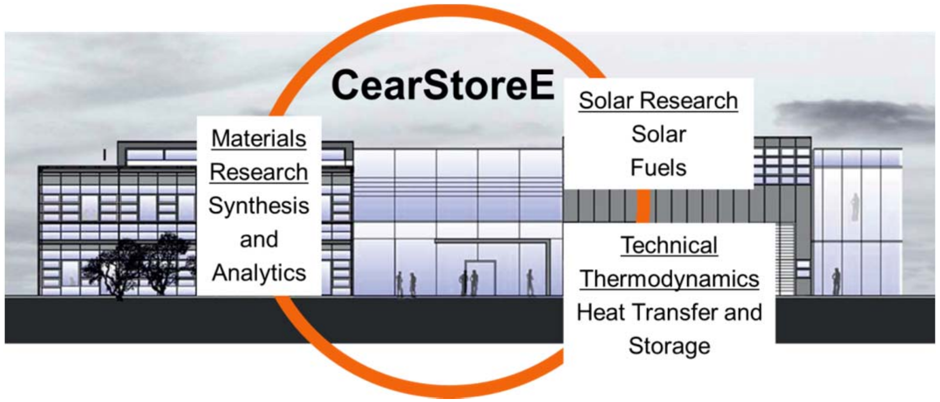


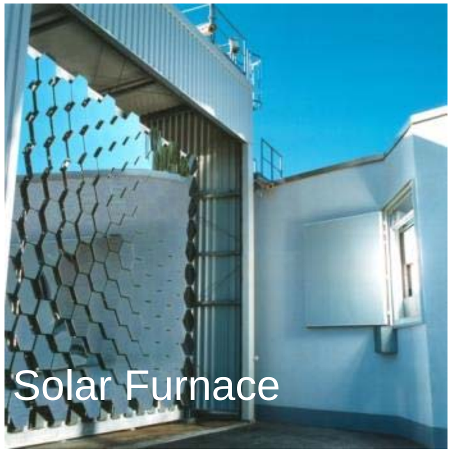
160 staff, > 15 M€/a, 4 sites

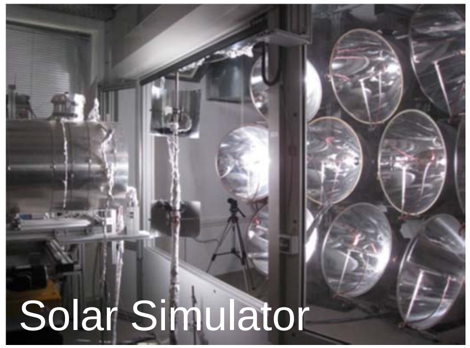
Large scale facilities











Department of Solar Chemical Engineering

Head
Organisation
Strategy
Representation in boards

Group High temperature CE
Solar tower >500°C

Solar Fuels
Solar Materials

Group Low temperature CE
Reactors up to Parabolic troughs < 500°C

Heat transfer fluids
Solar fuels
Water treatment
SOWARLA GmbH

26 Co-workers from Brazil, France, Germany, Greece, India, Italy, Canada, Mexico, Tunesia and the USA + 10 Grad-Students, 65% external funding

DLR-DAAD PhD, and Post-Doc Program

Technical Optimization in all Dimensions necessary

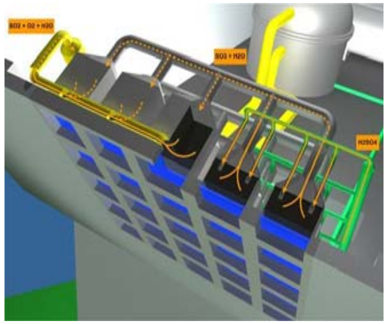
$10^4 - 10^2$ m
Solar Plant

Site

Solar field

Simulation

Environmental impact



$10^2 - 10^1$m
Receiver

Design

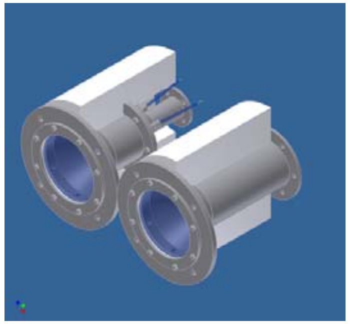
Simulation

Construction

Testing

Next-Generation-

Development



$10^1 - 10^{-2}$m
Receiver-
components

Materials

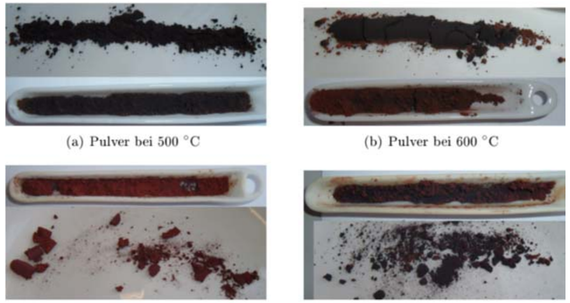
Design

Heat and

Mass transport

Simulation

Testing and Develpment



(a) Pulver bei 500 °C
(b) Pulver bei 600 °C
(c) Pulver bei 800 °C
(d) Pulver bei 900 °C

$10^{-2} - 10^{-8}$ m
Reactive Systems

Simulation

Synthesis

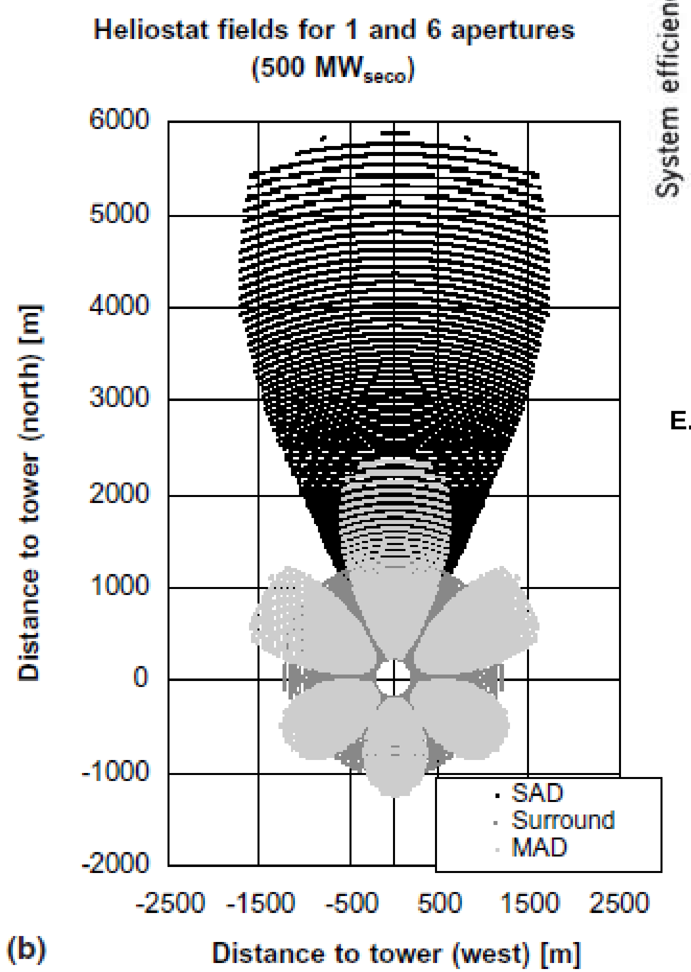
Chemical Charactristics

Physical Characteristics

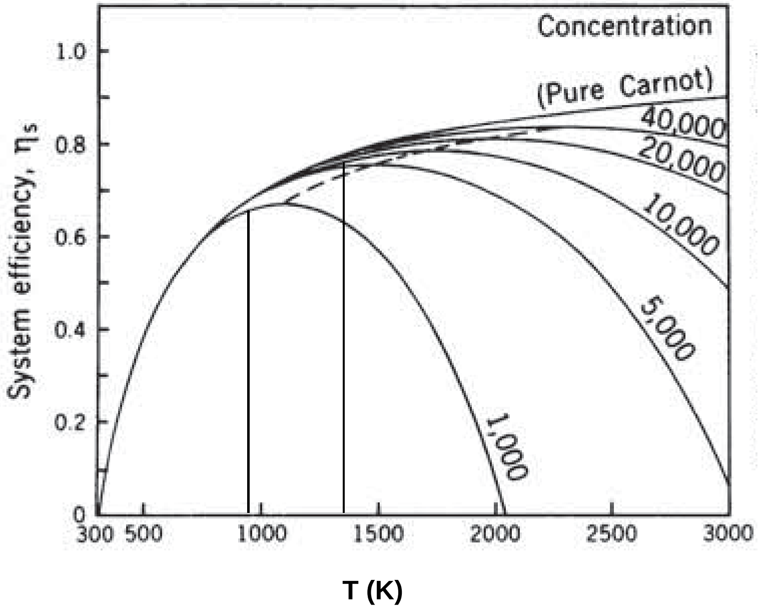
Solar Field Development

The field has to be designed for its application:

- Location
- Concentration ratio to achieve the Process temperature
- At high concentration (1000 suns) secondary optics have to be taken into account



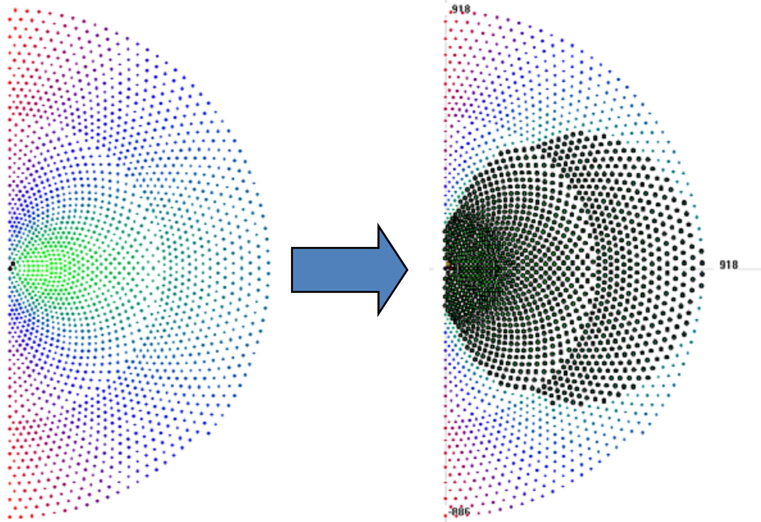
M. Schmitz et al., Solar Energy 80 (2006) 111–120.



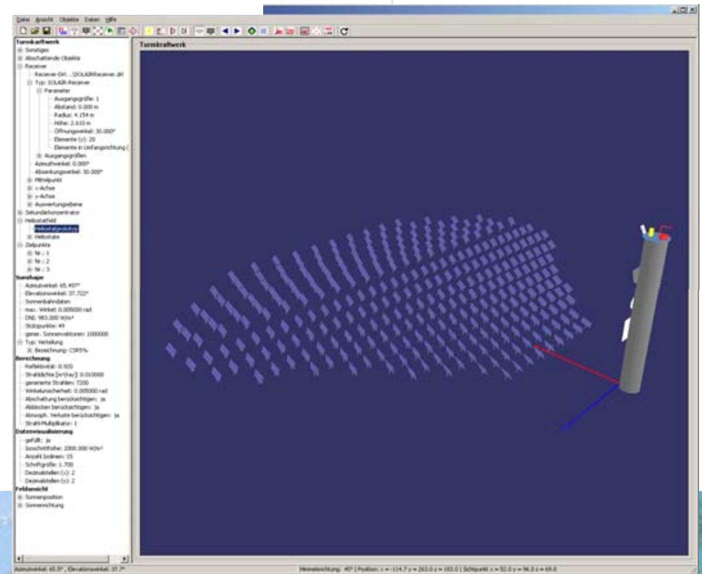
E.A. Fletcher, R.L. Moen, Science, 197 (1977) 1050-1056.

Simulation Tool Development
for Solar Tower Systems

- heliostat field layout

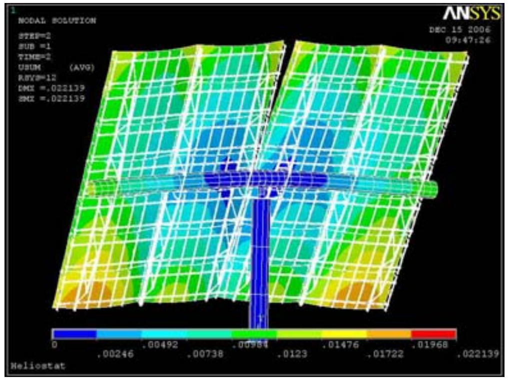


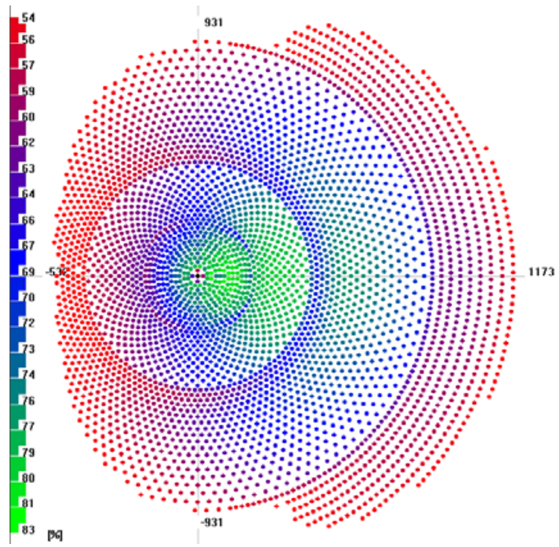
- performance simulation
    - flux distribution
    - aim point strategy
    - efficiency

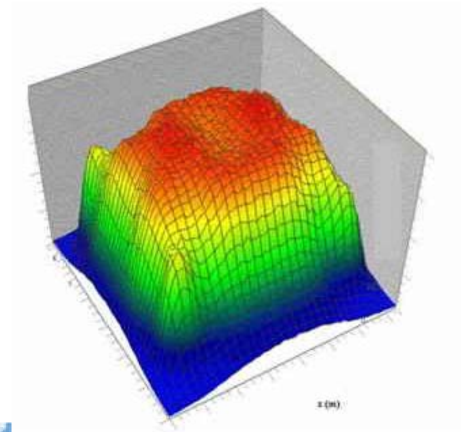


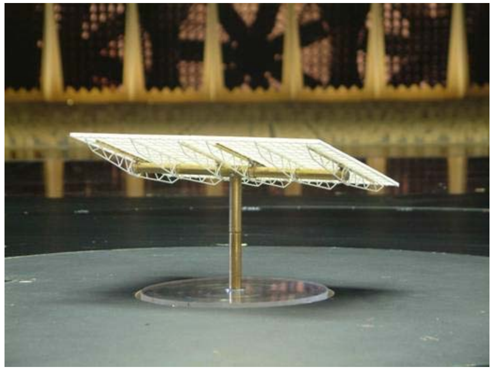
Heliostat R&D

- heliostat and field simulation
- structural analysis
- load analysis
- qualification
- control
- operation strategy



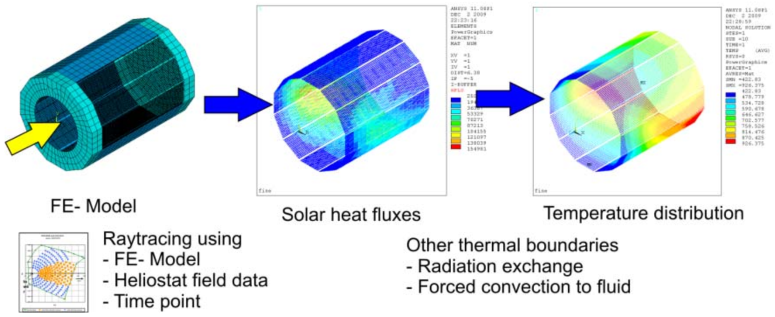


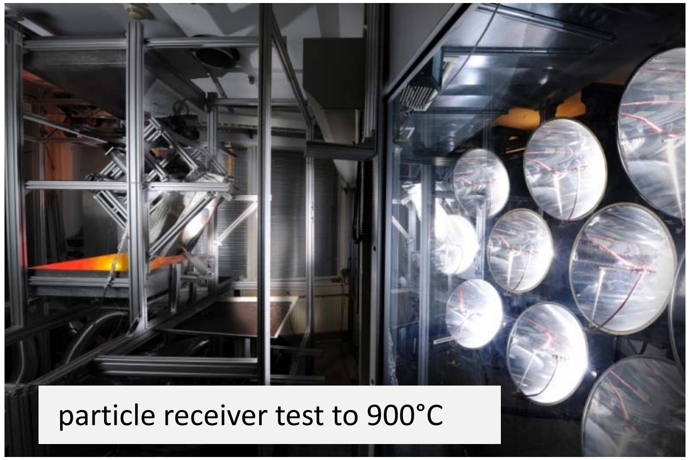


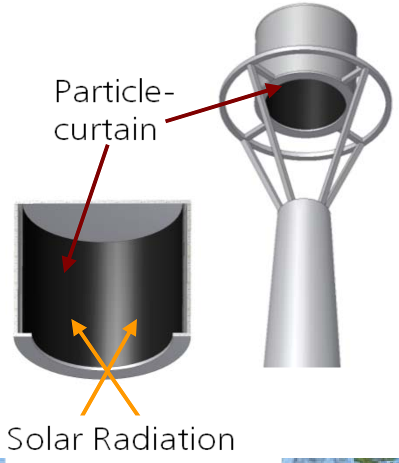


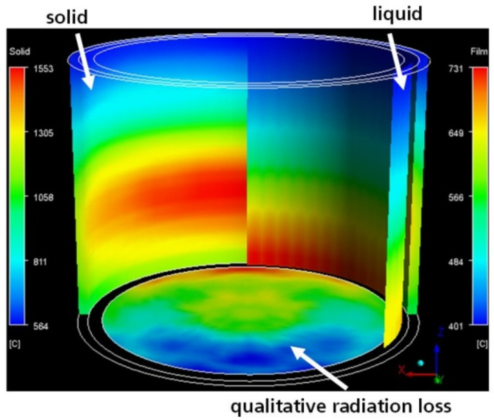
Receiver Technology R&D

- development / technology transfer
  - open volumetric air receivers
  - pressurized air receivers
- extension to liquid heat transfer media
  - e. g. molten salt
- innovative concepts: direct absorption receivers





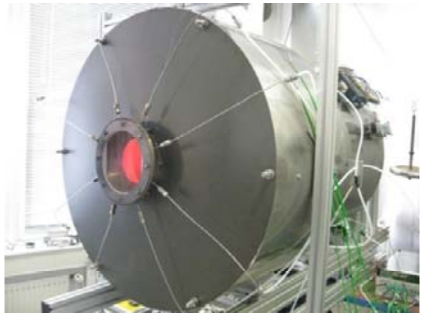


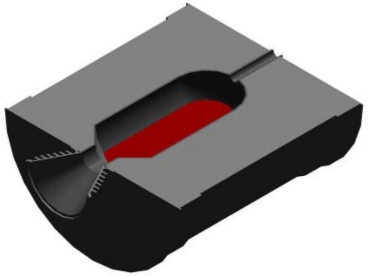


Receiver – Concepts for Solar Chemistry

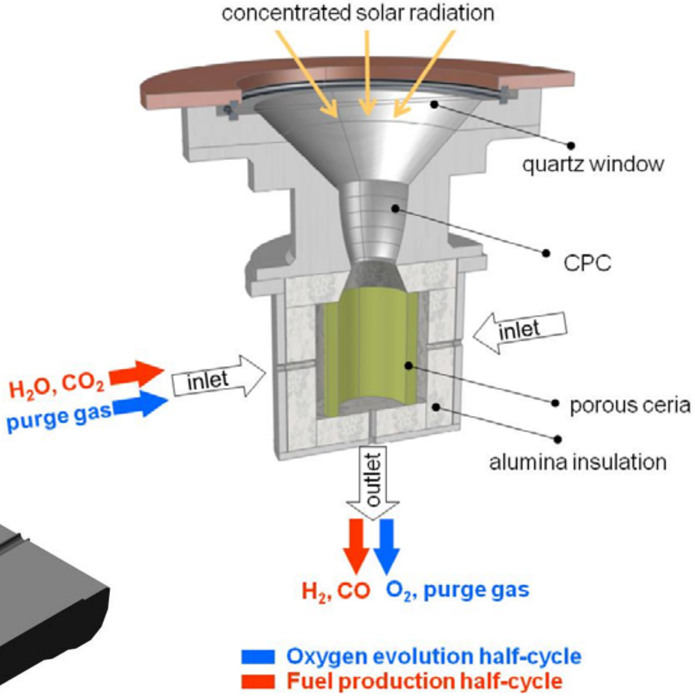
- Challenges:
  - Temperature
  - Corrosion
  - Abrasion
  - Process operation

- Goals:
  - Efficiency
  - Durability
  - Cost

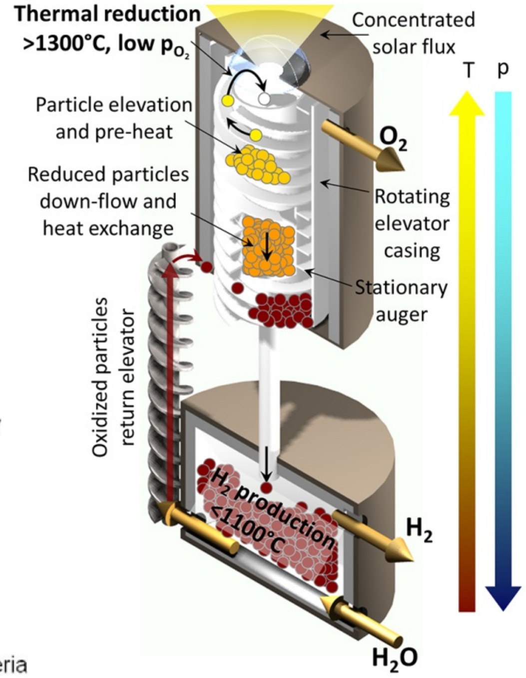




German Project
Solar heated rotary kiln, DLR

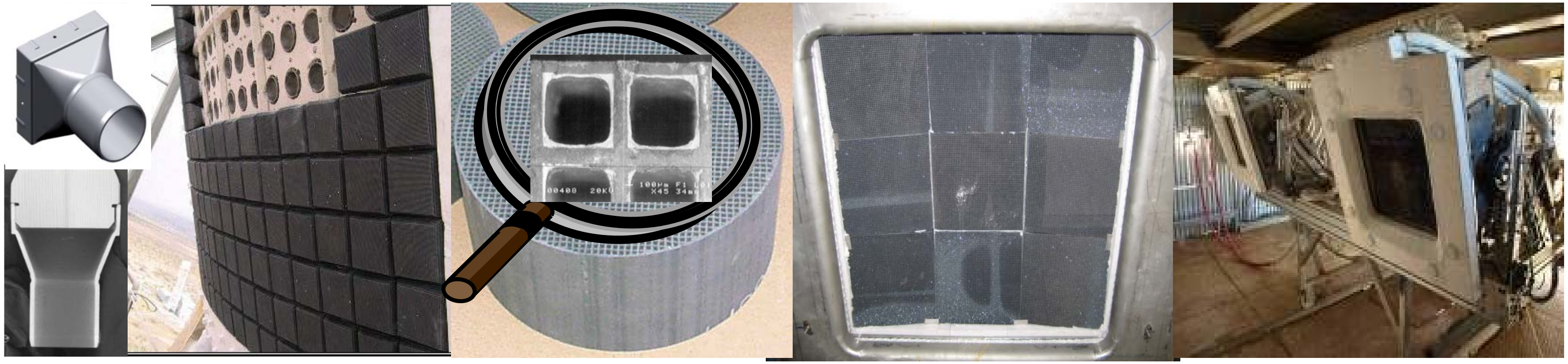


European Project
Solar heated Cavity-Gas Receiver
with porous Ceramic structur
A. Steinfeld et al., ETH Zürich



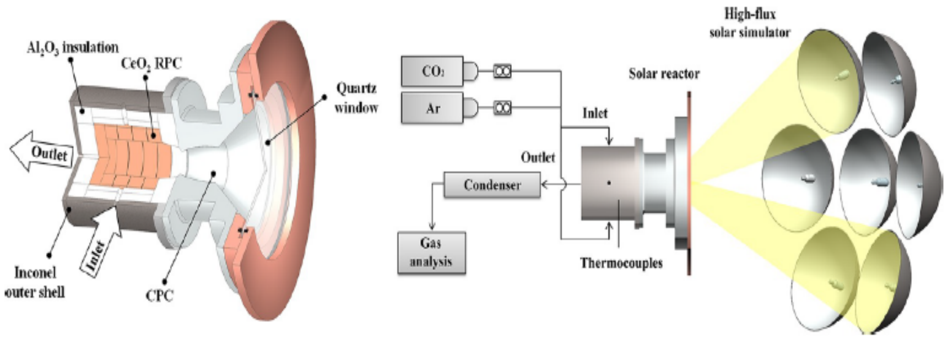
DoE Project with DLR participation
Solar heated Partikel-Receiver
I. Ermanoski et al., Sandia Natl. Lab.

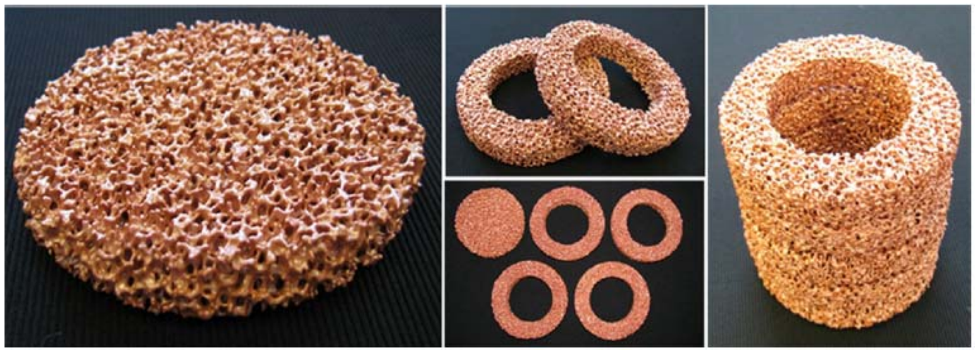
Solar Receiver Components and reactive Systems



C. Agrafiotis, M. Roeb, A.G. Konstandopoulos, L. Nalbandian, V.T. Zaspalis, C. Sattler, P. Stobbe, A.M. Steele, Solar water splitting for hydrogen production with monolithic reactor, Solar Energy, 79(4), 409-421, (2005).

Reactive coated structures and structures made from reactive materials





P. Furler, J. Scheffe, M.Gorbar, L. Moes, U. Vogt, A. Steinfeld, Solar Thermochemical CO_2 Splitting Utilizing a Reticulated Porous Ceria Redox System, Energy & Fuels, 26(11), 7051-59, (2012).

Overview of DLR CSP simulation tools

- DLR simulation tools cover all levels of CSP simulation

GREENIUS: analysis of performance / economics of renewable energy systems

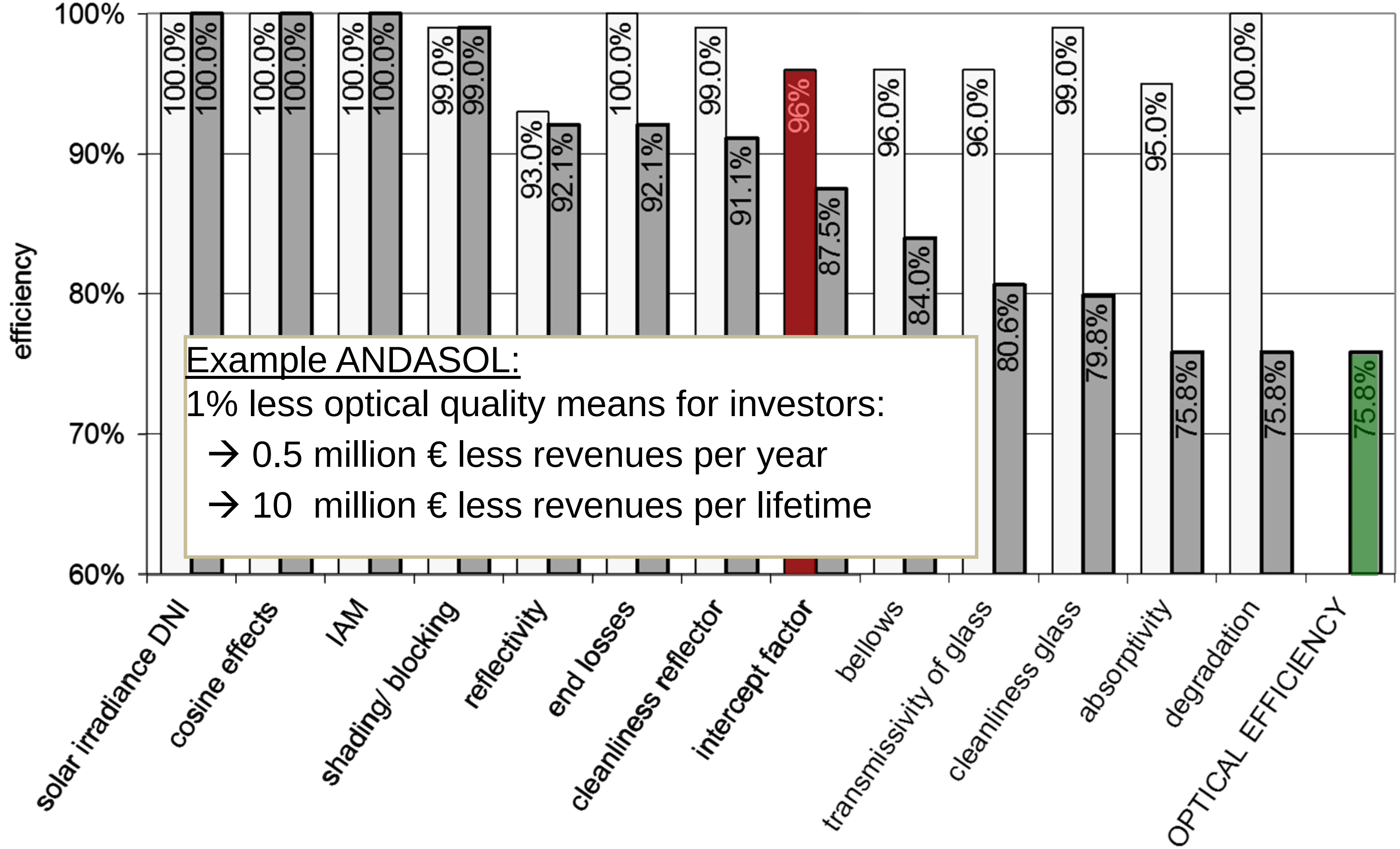
ebsSolar®: detailed performance analysis of CSP systems

component layout:
- concentrators (parabolic trough, Fresnel, heliostats)
- receivers

system layout optimization:
- solar field, receiver
- power block
- storage

transient system simulation:
- real-time, high resolution performance simulation
- coupling of components and control

Qualification - Motivation
Efficiency Chain, Example: Parabolic Trough



QUARZ® – Center
Test and Qualification Center for CSP Technologies

- Strong impact on the **performance and cost efficiency**:
  - CSP component quality and durability
  - their interaction in the overall system
  - and the meteorological conditions each

- Development of **measurement techniques and devices**
- Evolution of **guidelines and standards**
  - testing methods
  - quality criteria

- Customer oriented services

  → Fundamental information for industry to
    - **Improve** quality, performance → **competiveness**
    - **Proof** of product quality → successful **market entry / bankability**

  → Consulting and training

Efficiency comparison for solar hydrogen production from water (Siegel et al., 2013)*

Process	T [°C]	Solar plant	Solar-receiver + power [MW_{th}]	η T/C (HHV)	η Optical	η Receiver	η Annual Efficiency Solar – H_2
Elctrolysis (+solar-thermal power)	NA	Actual Solar tower	Molten Salt 700	30%	57%	83%	13%
High temperature steam electrolysis	850	Future Solar tower	Particle 700	45%	57%	76,2%	20%
Hybrid Sulfur-process	850	Future Solar tower	Particle 700	50%	57%	76%	22%
Metaloxide two step Cycle	1800	Future Solar dish	Particle Reactor < 1	52%	77%	62%	25%

*N.P. Siegel, J.E. Miller, I. Ermanoski, R.B. Diver, E.B. Stechel, Ind. Eng.Chem. Res., 2013, 52, 3276-3286.

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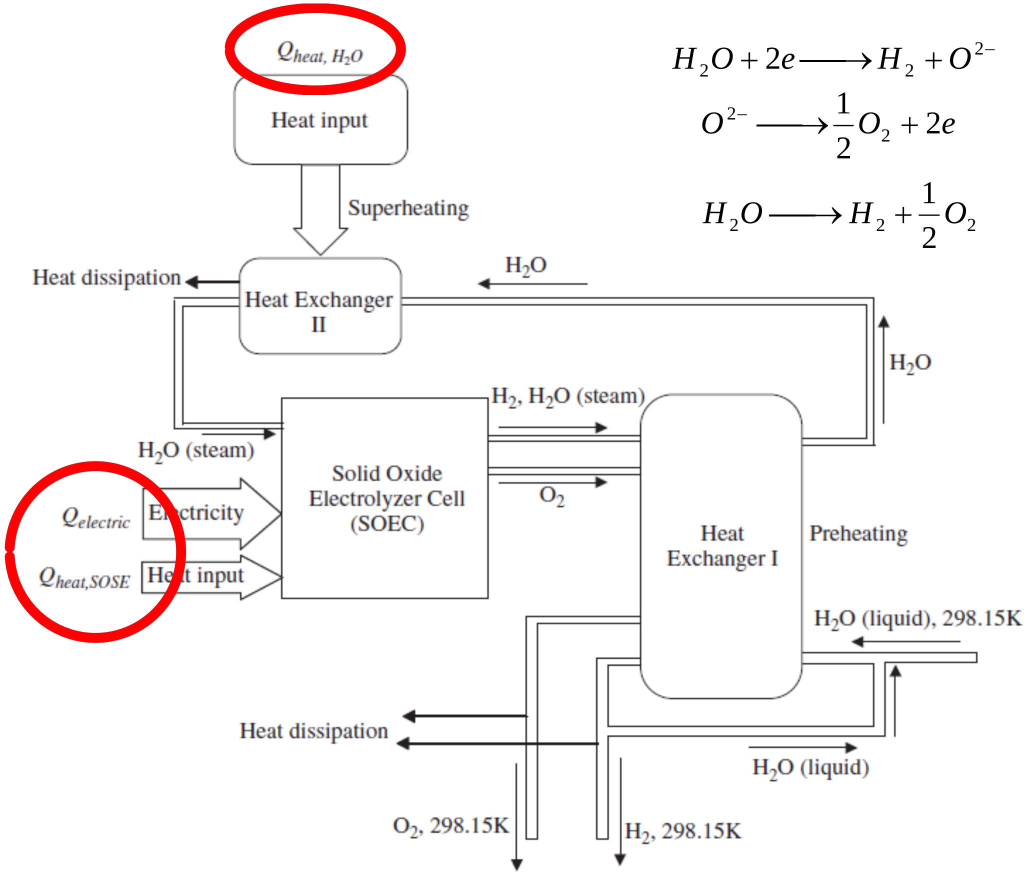
High temperature electrolysis process

- Temperature in the range of 600°C to 900°C are required to drive the electrolyser.
- Electricity and heat are supplied to the electrolyser to drive the electro-chemicals reactions.
- The waste heat from the H_2 and O_2 gas streams existing the cell is used to evaporate water.
- The H_2O stream is further heated by the second Heat exchanger to raise the temperature of the electrolyser.

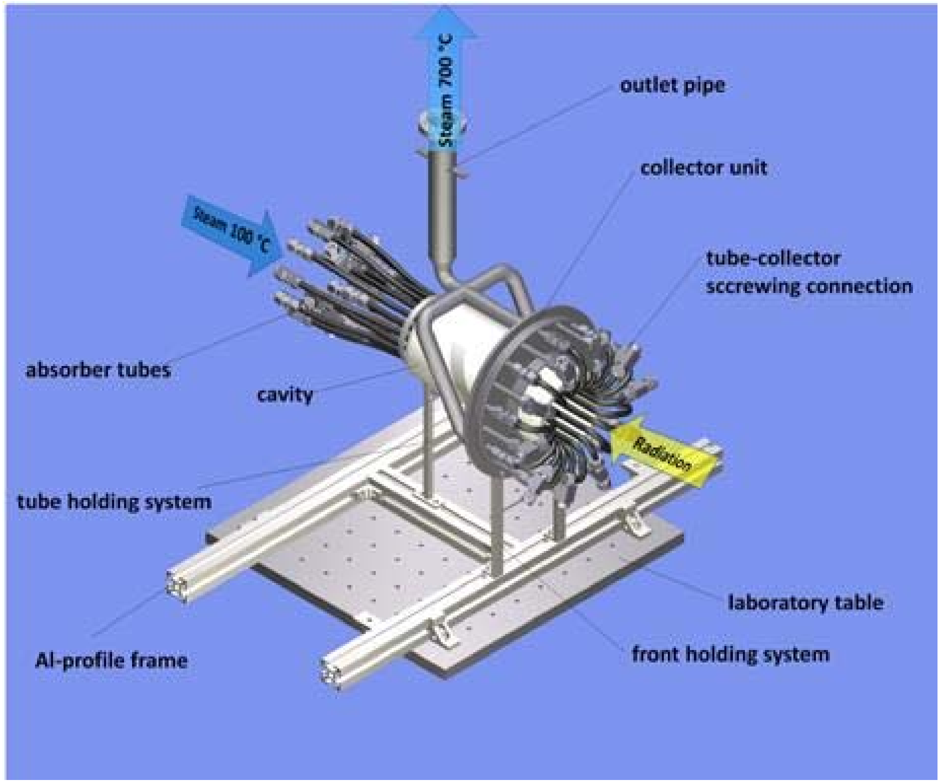
$$H_2O + 2e \longrightarrow H_2 + O^{2-}$$

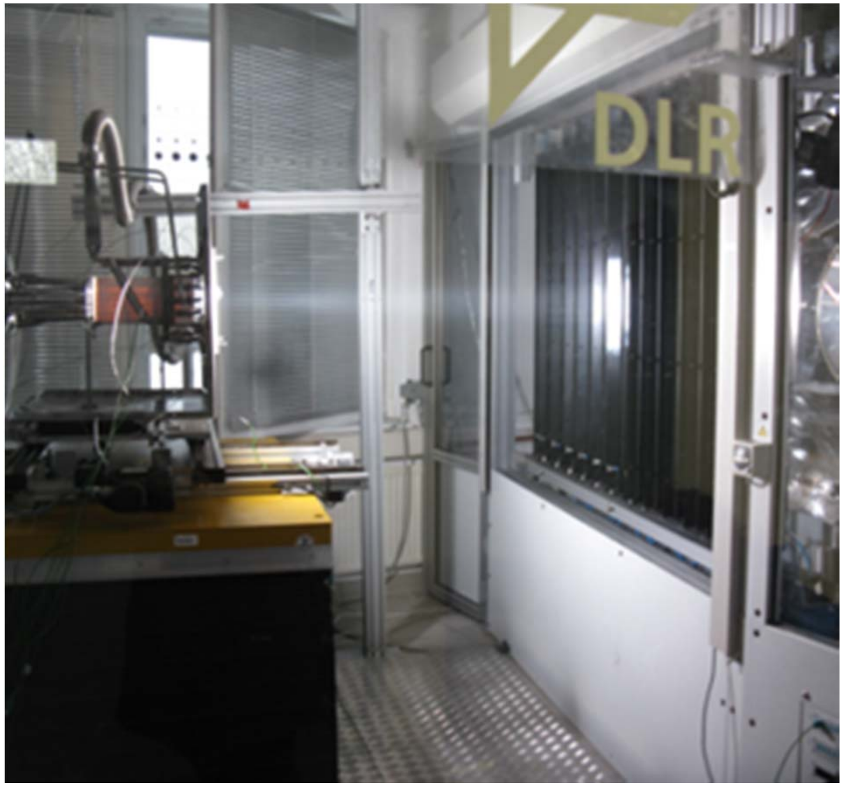
$$O^{2-} \longrightarrow \frac{1}{2}O_2 + 2e$$

$$H_2O \longrightarrow H_2 + \frac{1}{2}O_2$$



Solar Superheated Steam Generator for SOEC



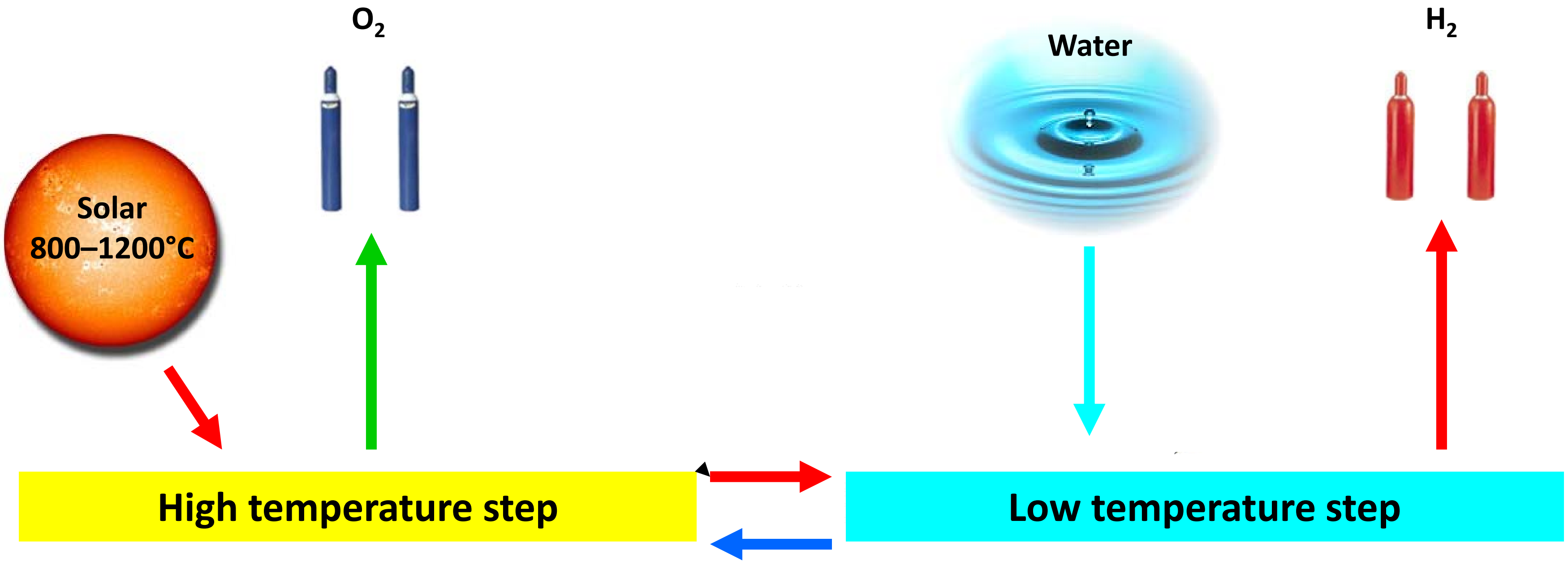


3D Design

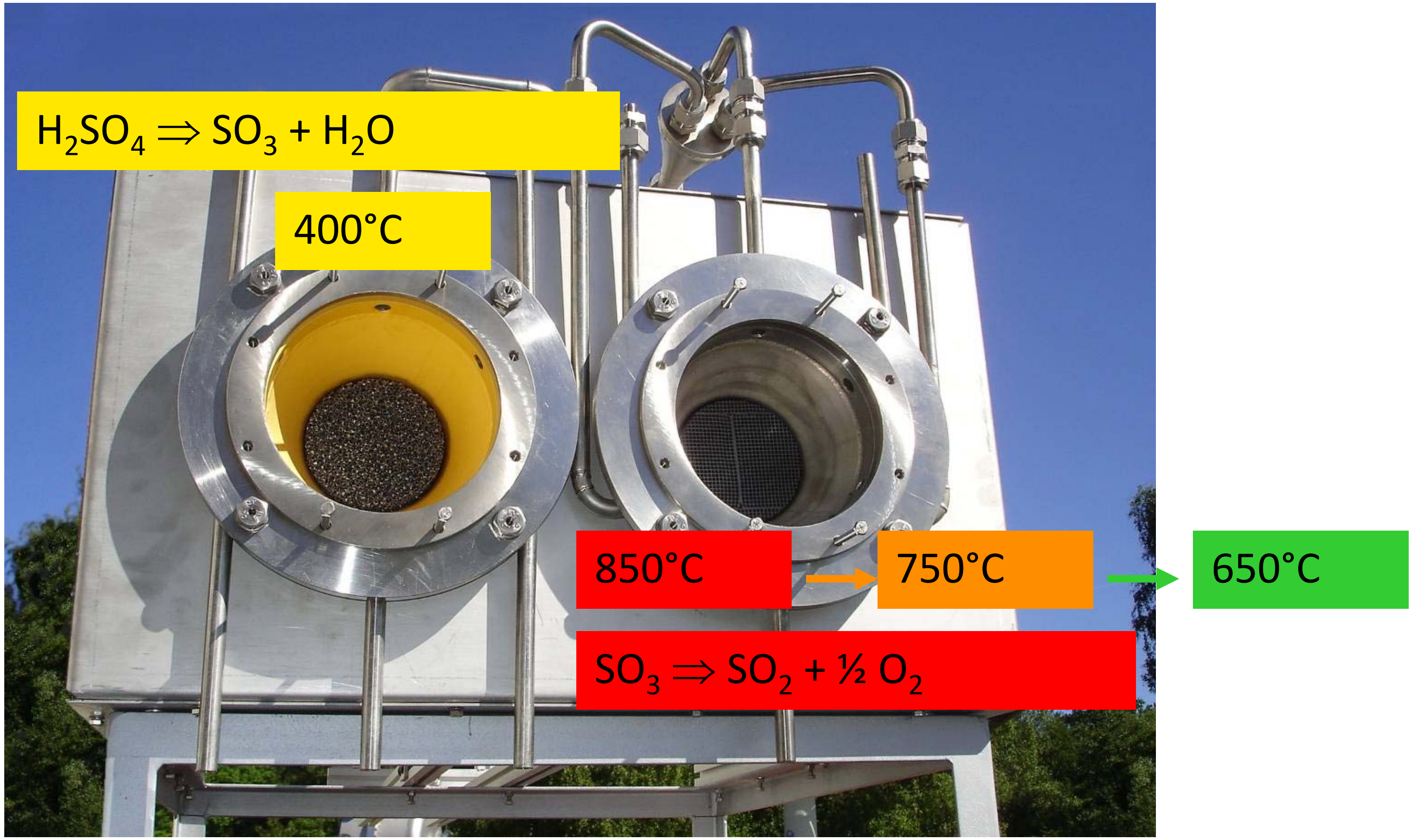
Operation in the solar simulator providing 5 kg/h steam at 700 °C

http://www.sophia-project.eu/

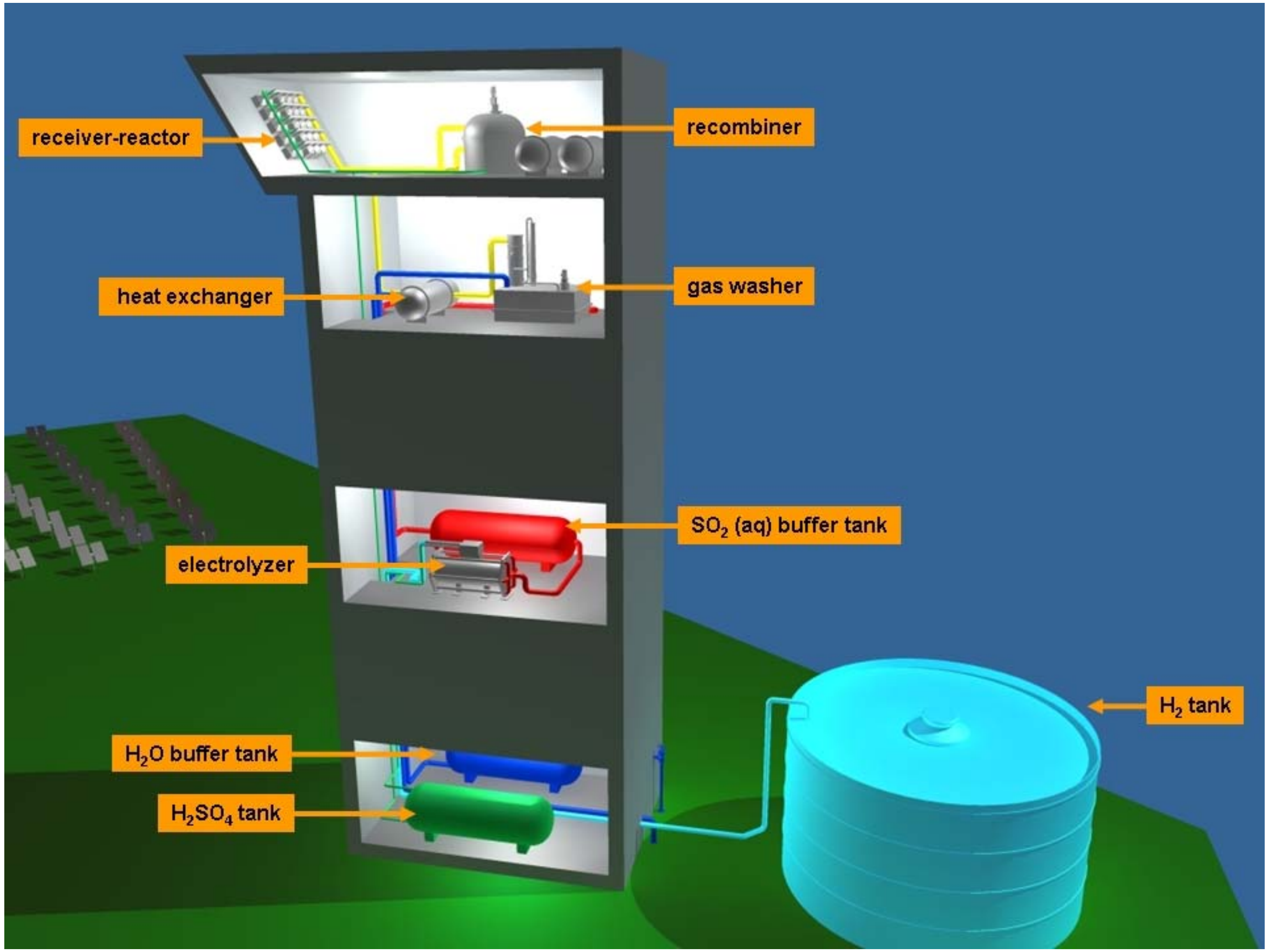
Hybrid Sulfur Cycle (HyS, Westinghouse)



Solar reactor for sulfuric acid decomposition



Implementation into a Solar Tower

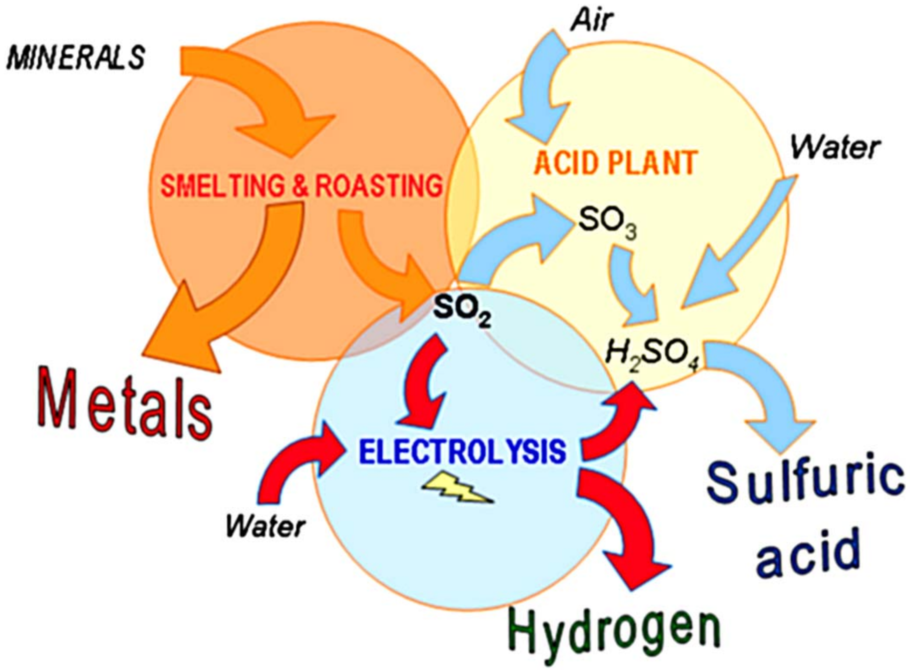


SOL2HY2 – Solar To Hydrogen Hybrid Cycles

- FCH JU project on the solar driven Utilization of waste SO_2 from fossil sources for co-production of hydrogen and sulphuric acid
- Hybridization by usage of renewable energy for electrolysis
- Partners: EngineSoft (IT), Aalto University (FI), DLR (DE), ENEA (IT), Outotec (FI), Erbicol (CH), Oy Woikoski (FI)
- >300 kW demonstration plant on the solar tower in Jülich, Germany in 2015

https://sol2hy2.eurocoord.com

Outotec[TM] Open Cycle (OOC)



- Utilization of waste SO_2 from fossil sources
- Co-production of hydrogen and sulphuric acid
- Hybridization by renewable energy for electrolysis

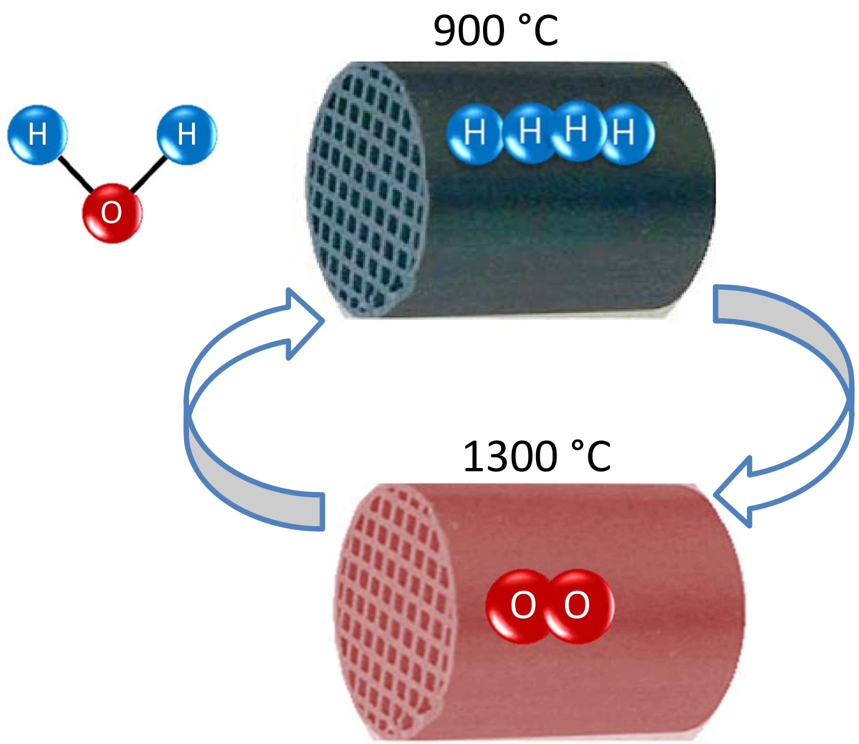
Example how a technology is developed
The HYDROSOL concept

1. Water Splitting

$H_2O + MO_{red} \rightarrow MO_{ox} + H_2$

2. Regeneration

$MO_{ox} \rightarrow MO_{red} + ½\ O_2$

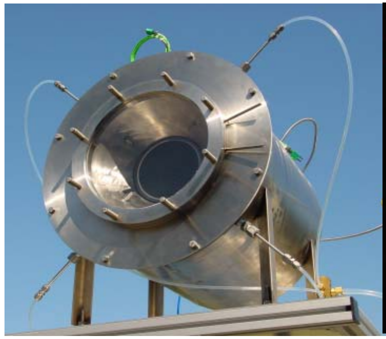
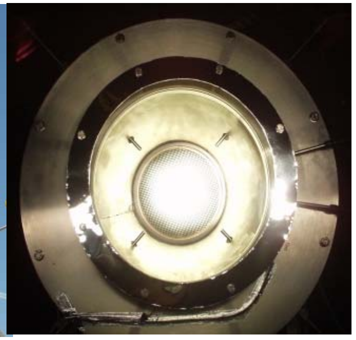


Net Reaction: $H_2O \rightarrow H_2 + ½\ O_2$

Hydrosol technology scale-up


2008:
Pilot reactor
(100 kW)

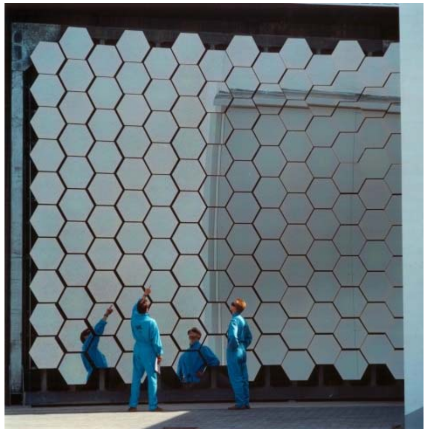

2005:
Continuous
H_2 production

2004:
First solar
thermochemical
H_2 production

PSA
solar tower

DLR
Solar
Furnace



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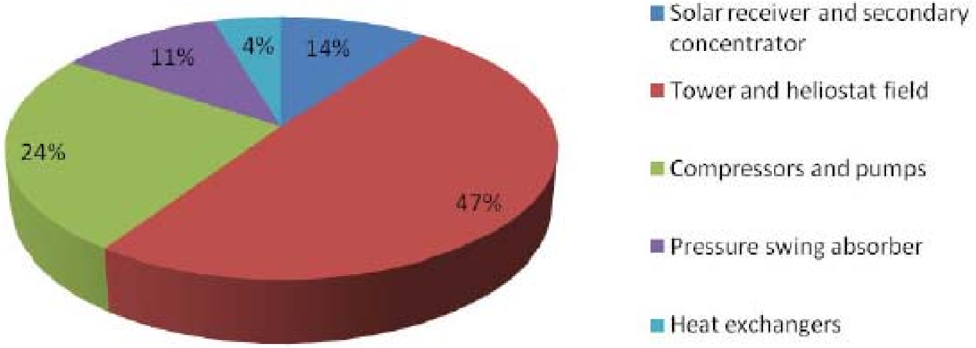
Solar fuels from thermochemical cycles- HYDROSOL 3D project- Main results Economic analysis of the demonstration plant

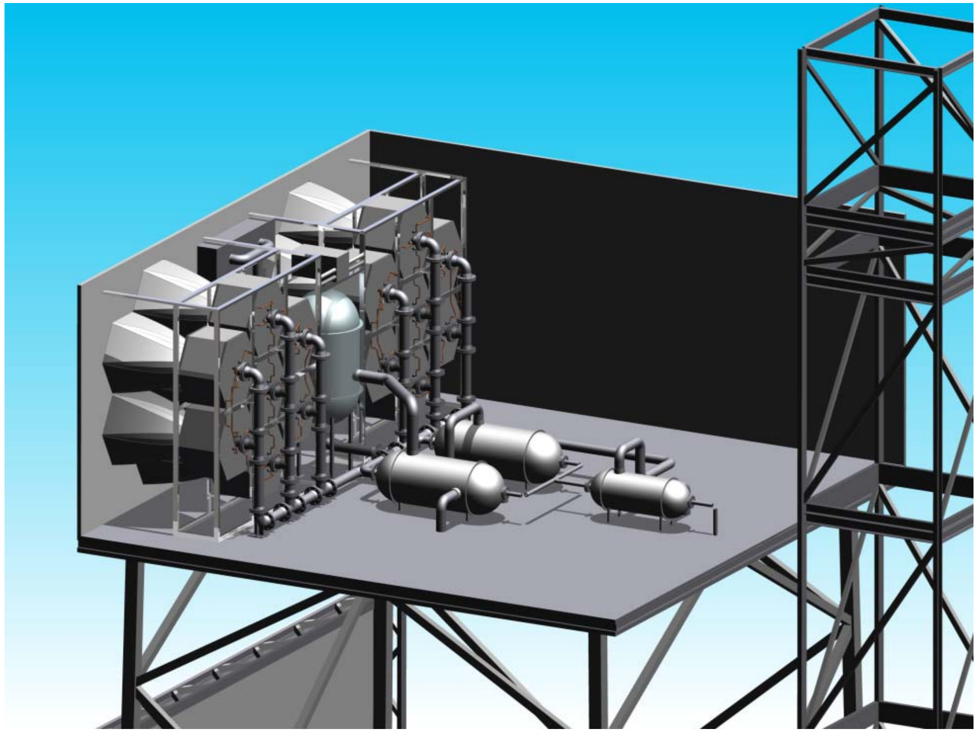
- Demonstration plant thermal energy input: 1 MW
- Cost calculation of the new designed reactor was carried out.
- Cost calculation of the overall process units was performed.
- More than half of process investment results from the solar system.

Component	Number of units	Cost per unit [€]	Total Cost [€]
Quartz plates	14	600	8400
Reactor modules	14	3000	42000
Secondary concentrator	14	12000	168000

Solar part incl. receiver-reactor[€]	1,406,847
Pressure swing absorber [€]	265,000
Compressors and pumps [€]	584,054
Heat exchangers [€]	110,493
Total cost [Mio. €]	**2.366**



HYDROSOL, HYDROSLOL 2, HYDROSOL-3D, HYDROSOL Plant

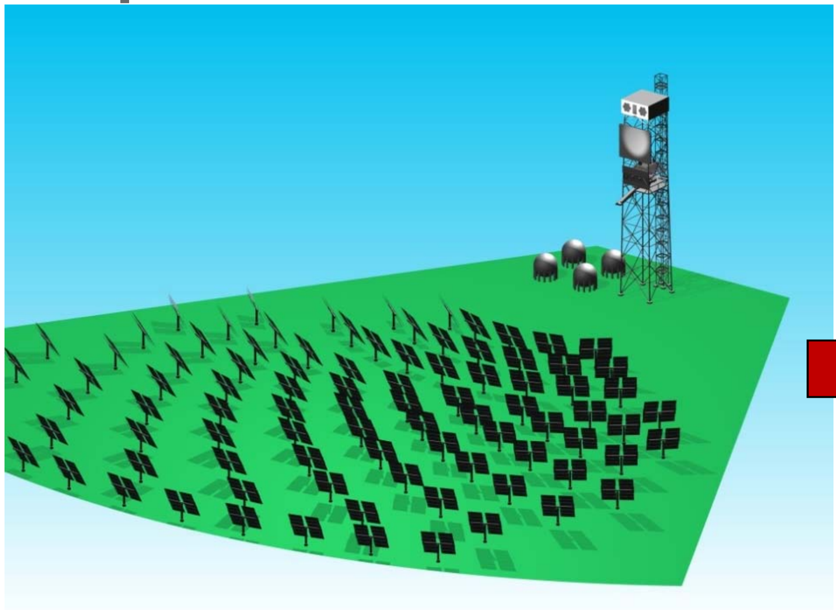


APTL (GR), DLR (DE), CIEMAT (SP), StobbeTech (DK), Johnson Matthey (UK), HyGear (NL), HELPE (GR)

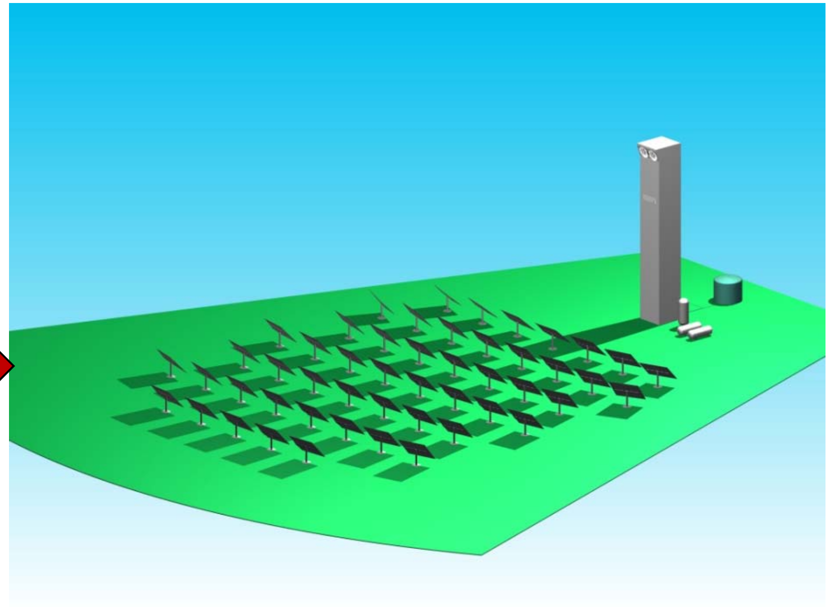
- 2002 Start HYDROSOL, EU FP5
- 2004 First solar hydrogen, DLR
- 2005 Quasi-continuous solar hydrogen, DLR
- 2008 HYDROSOL 2, EU FP6, 100 kW demonstration CRS Tower PSA, Spain
- 2013 HYDROSOL-3D, FCH JU, Design of a 1,5 MW demonstration plant ready
- 2014 HYDROSOL PLANT, FCH JU
- 2016 Operation of the 750 kW Demonstration plant, CRS Tower, PSA, Spain

http://hydrosol-plant.certh.gr/

Next Step:
Specific Solar Fuel Demonstration Tower needed!



CRS Tower PSA, Spain
2008 and 2015



Solar Fuels Tower, Location?
2020

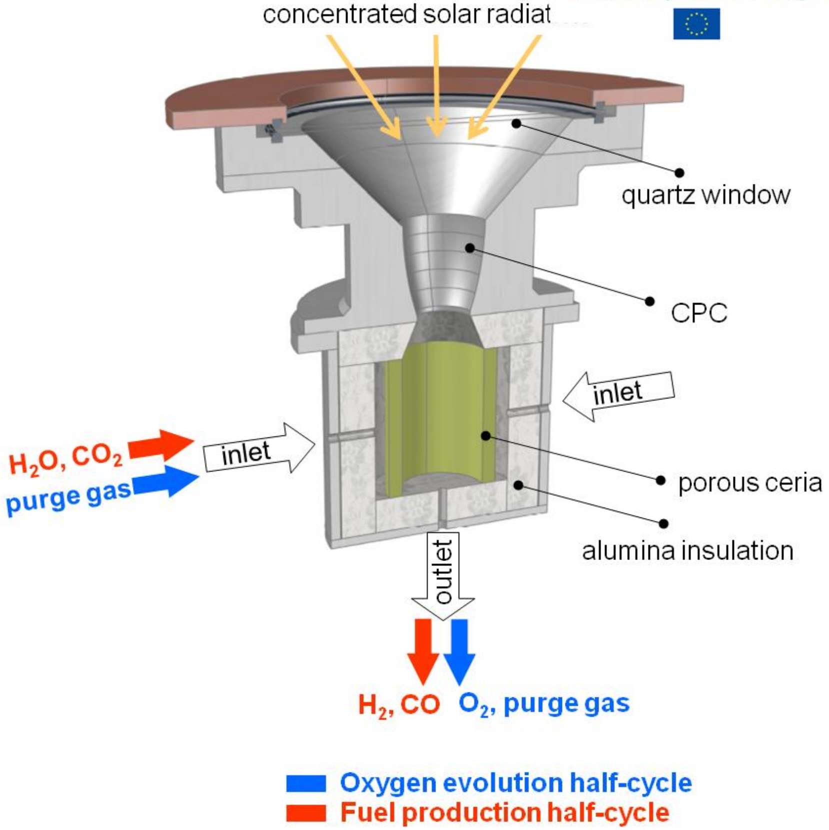
- High concentration > 1000
- Heliostats fit to receiver size
- Field control adapted to fuel production processes

SOLAR-JET
Zero-carbon jet fuel from sunlight

H_2O/CO_2-Splitting Thermochemical Cycles

Solar Production of Jet Fuel

- EU-FP7 Project SOLAR-JET (2011-2015)
- SOLAR-JET aims to ascertain the potential for producing jet fuel from concentrated sunlight, CO_2, and water.
- SOLAR-JET will optimize a two-step solar thermochemical cycle based on ceria redox reactions to produce synthesis gas (syngas) from CO_2 and water, achieving higher solar-to-fuel energy conversion efficiency over current bio and solar fuel processes.
- **First jet fuel produced in Fischer-Tropsch (FT) unit from solar-produced syngas**!



Int. J. Heat & Fluid Flow 29, 315-326, 2008.
Materials 5, 192-209, 2012.

Partners: Bauhaus Luftfahrt (D), ETH (CH), DLR (D), SHELL (NL), ARTTIC (F)
Funding: EC

http://www.solar-jet.aero/

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Thank you very much for your attention!

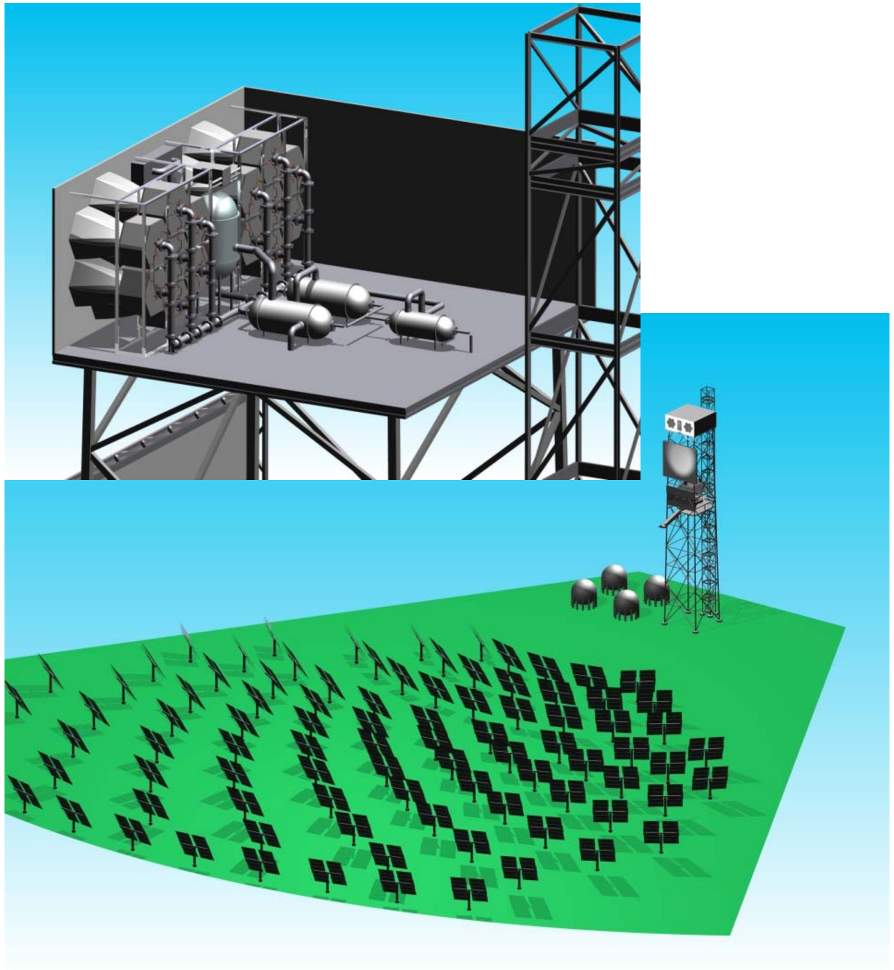
Summary

- R&D in Europe is strongly based on international cooperation
- The cooperstion is between countries in the European Research Area as well as world wide
- The cooperation is between universities, research centres and industry
- There is a strategy for R&D that defines the direction

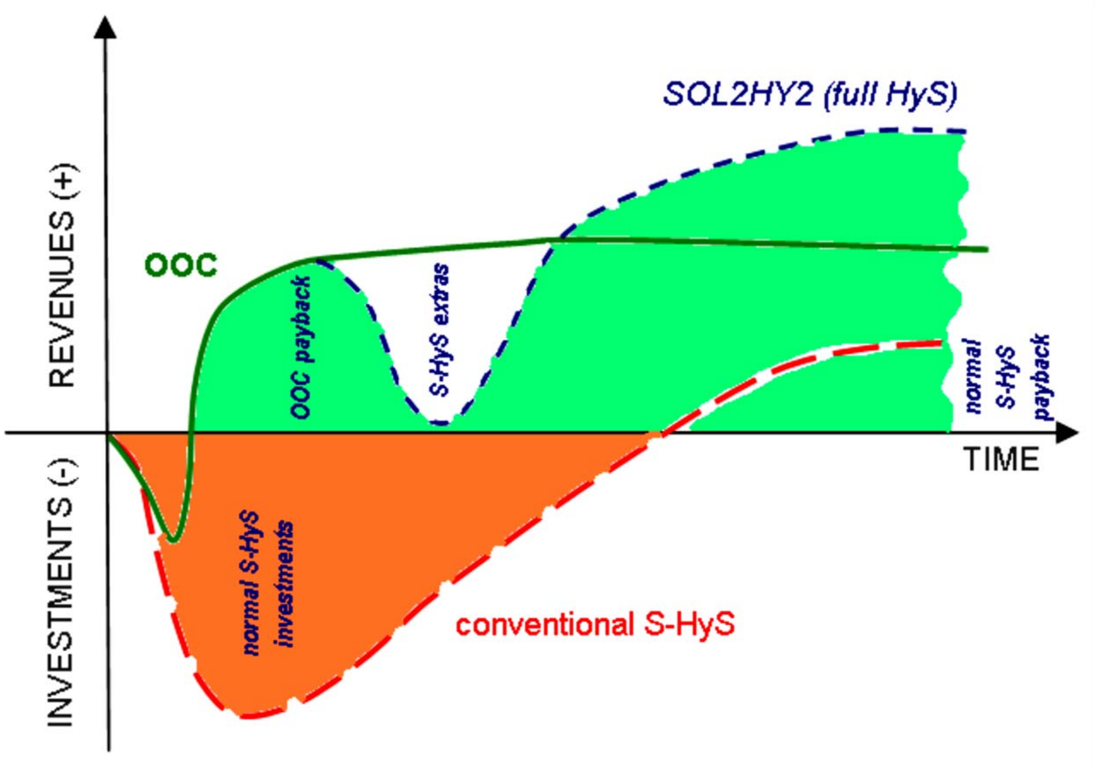
DLR

Hydrosol Plant - Design for CRS tower PSA, Spain

- European FCH-JU project
- Partner: APTL (GR), HELPE (GR), CIEMAT (ES), HYGEAR (NL)
- 750 kW_{th} demonstration of thermochemical water splitting
- Location: Plataforma Solar de Almería, Spain, 2015
- Use of all heliostats
- Reactor located on the CRS tower
- Storage tanks and PSA on the ground



Investments vs. revenues



- Reduction of initial investments
- Financing of HyS development by payback of OOC
- Increase of total revenues